Various Surface Treatment Methods and Their Effects on Properties of Recycled Concrete Aggregate

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Abstract-*Due to Urbanization in countries like India, a large quantity of construction and demolition waste is generated every year. Hence the disposal of this waste in large quantity has become a serious problem as it requires huge space for dumping. Looking at the infrastructure developments in our country, in future it will be necessary to find new source of aggregate for the production of concrete due to increase in its demand and also comparatively limited supply of natural aggregate. One good solution is to obtain Recycled concrete aggregate (RCA) from the material that have been previously used in construction. The properties of RCA are different from natural aggregates. The presence of mortars in the RCA is a main reason to lower the quality of RCA as compared to natural aggregates.*

In this paper various treatments like water washing, heating and acid soaking are used for removal of attached mortar and improve the properties of RCA. After the treatment on RCA, mix design is done for M35 and M40 grade of concrete and the properties of concrete were tested and compared with natural aggregates concrete. Concrete mixes are prepared using natural aggregate, recycled aggregate, recycled aggregate treated with HCl, recycled aggregate obtained after heating treatment. The physical and mechanical properties of these aggregates, and their strength and performance are determined. However, results show that there is improvement in properties like workability, compressive strength and split tensile strength when treated aggregates were used.

Keywords-Natural Aggregate (NA), Recycled aggregate (RA), Surface treatment method, Recycled aggregate concrete (RAC), Recycled concrete aggregate (RCA)

I. INTRODUCTION

Due to growing urbanization, large amount of construction is seen all around. The old structures are being demolished and huge towers are occupying that place. The large quantity of waste is resulting from such demolitions. This huge amount of Construction and Demolition (C&D) waste creates a significant impact on the environment and society. The impact of the fast growth of construction industry indirectly requires a considerable amount of production and consumption of natural aggregates. Accordingly aggressive consumption will deplete such resource if proper planning and control measures are not implemented. Thus the next step of shifting toward the use of recycled aggregates could reduce the dependence of the construction industry on natural aggregates and thus protect natural aggregate reserves and still ensure sustainable development. The presence of mortar remains in the recycled concrete aggregates is the main reason for deteriorated RCA quality as compared to natural aggregates because adhered mortar is characterized as porous and possesses numerous micro cracks. In this paper three methods for treatment of RCA are used that are acid soaking, heating and water washing for removing mortar from RCA thereby improving quality of RCA. The results show comparison of physical and mechanical properties of these treated aggregates with 100% RCA and natural aggregate.

Vivian W.Y.1 (2007) they study three pre-soaking treatment approaches namely ReMortarHCl, ReMortarH2SO4 and ReMortarH3PO4 in reducing the mortar attached to RA. They found RA has improved with reduction in water absorption, without simultaneous exceeding the limits of chloride and sulphate compositions after the treatment. This work has also compared the compressive strength, flexural strength and modulus of elasticity of concrete made from the approaches, which shows marked improvements in quality when compared with those using traditional approaches.

Revathi Purushothaman2 (2014) studied the effect of chemical as well as mechanical treatment approaches in reducing the mortar attached to aggregate are compared. The physical and mechanical properties of these aggregates, and their strength and performance are determined. They conclude that the results shows that treatment with H2SO4 and heating and scrubbing yield aggregate with reduced water absorption and other desired properties of natural aggregate.

A.Akbarnezhad3 (2011) proposed Microwave treatment method for processing recycled aggregate. Their results confirmed that microwave heating may be effectively used to partially remove the cementitious mortar through developing high temperature gradients and thus high thermal stresses within the mortar.

Poon et al4 (2002) developed a technique to produce concrete bricks and paving blocks from recycled aggregates. The test result showed that replacing natural aggregate by 25% to 50% had little effect on the compressive strength, but higher levels of replacement reduced the compressive strength.

II. MATERIALS USED

The materials used in this experimental setup are ordinary portland cement, natural coarse aggregate, recycled coarse aggregate, sand, water and admixture.

1. Cement:

Ordinary Portland Cement (OPC) of 53 grade confirming to Indian standard IS 12269-1987 is used.

2. Aggregate:

Fine Aggregate:

The river sand is used as fine aggregate confirming to zone-1 of IS: 383.

Coarse Aggregate:

The crushed aggregate was used from the local quarry. In this experiment the aggregate particles passing through 20mm and retained on 4.75mm I.S sieve are used as coarse aggregate.

Recycled coarse aggregate:

Recycled aggregate has been collected from demolished building as shown in Figure 2.2. The old concrete lumps were broken into smaller pieces on the site. This was further manually broken down to pieces using sledge hammer and the steel reinforcements, dowels and tie bars were removed.

Figure 1. Site from where RCA collected

3. Admixture:

High performance superplasticiser with high water reduction and long workability retention was used for M35 and M40 Grade of concrete.

4. Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. It helps to provide the strength to concrete. The quantity and quality of water is also plays an important role from strength perspective.

III. SURFACE TREATMENT METHODS

For the improvements of RCA the treatments have a clear goal, which is to diminish the limitations of the recycled aggregates and improve its qualities. It is possible to improve the properties of recycled aggregates by suitable treatment systems.

1. Acid soaking of RCA

To remove the loosely adhered mortars from the recycled aggregates, the aggregates were treated with hydrochloric acid (HCl) with concentration of molarities of 0.8M. The method involves the application of hydrochloric acid (HCl) as acidic solvent in degradation action for removal of crumbs or loose adhered mortars attached to the original recycled concrete aggregate.

The aggregate was immersed in acidic solvents for 24 hours. The container was occasionally shaken to ensure a more efficient reaction of acid in the removal of loose particles attached to the original aggregate. Then the recycled aggregate was taken out and washed thoroughly with water to remove the acidic solvents.

Figure 2. Acid treatment of RCA

2. Thermal heating of RCA

In this method the recycled aggregate was put in tray and kept in oven at a temperature of around 1500 for 24 hours, to remove attached mortar of recycled concrete aggregate, during this thermal stresses generated through thermal expansion are used to fracture and thereby remove the mortar present.

3. Water washing of RCA

The RCA were washed by pressure washing. This is done so as to remove the mortar adhered to the aggregates. The RCA were washed for 15 to 20 minutes.

IV. METHODOLOGY USED

The experimental program was designed to compare the mechanical properties i.e. compressive strength, split tensile strength of concrete with M35 and M40 grade of concrete. Concrete mixes were prepared with RA treated with HCl, RA treated with water, and RA treated with thermal method and is designated as RACHCl, RACWater, and RACThermal, respectively.

1. Mix Proportions:

Concrete mixes were designed for M35 and M40 grades with water cement ratio of 0.40 as per IS code 10262-2009. The proportions of constituent materials for two Mixes are presented in table 4.1.

2. Specimen preparation

A total of five series of concrete mixes were prepared and 60, 150-mm size cubes and five 150-mm diameter, 300-mm long cylinders were cast in each of the mix series for M35 and M40 grade of concrete. These test specimens were cured in water until the age of testing. The compressive strength of the cube specimen was determined at 3, 7, 14, and 28, days of age and the split tensile test of the cylinder specimen was determined at 28 days of age. used to test 28 days flexural strength of specimens

Table 1. Concrete mix proportion

Grade of Concrete	w/c ratio	Cement (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
M35	0.4	340	922	1126	140
M40	0.4	350	898	1143	140

V. EXPERIMENTAL RESULTS

1. Workability

The workability of fresh concrete mixes was determined by slump test and the results are presented in Table 5.1. The slump value of 90 mm was obtained in the natural aggregate concrete and only 50 mm obtained in recycled aggregate concrete. Workability of concrete mixes prepared with treated recycled aggregate is higher than normal RAC and maximum workability of 80 mm was witnessed in RACHCl.

The workability of recycled concrete is reduced because the mortar from the original concrete makes the recycled aggregate more porous and absorptive than its natural counterpart, the absorption capacity of recycled aggregate is nearly more than two times of natural aggregates absorption capacity. Workability of concrete mixes prepared with treated RA is higher than normal RAC.

2. Compressive Strength:

For Compressive strength test the specimens having dimensions of 150 mm x 150 mm x 150 mm were used. These specimens were tested after 3, 7, 14 and 28 days curing. The measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross sectional area calculated from mean dimensions of the section and shall be expressed to the nearest N/mm2. Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete. By this single test one judge that whether concreting has been done properly or not. Load should be applied gradually at the rate of 140 kg/cm2 per minute till the specimens fails.

The compressive strength can be calculated by dividing the max load applied to the area of the cube. This is given by the formula,

$$C = P/A$$

where,
P = Max load applied to the specimen
A = Area of cross section of the specimen

Table 5.2 and 5.3 shows the results of the 3, 7, 14 and 28-days compressive strength of concrete. It is found that the compressive strength of RAC is lesser than NAC. This indicates that the replacement of NA with RCA results lower compressive strength. This is due to the presence of loose mortar on RCA which results weak interfacial transition zone and higher water absorption due to adhered mortar.

The experimental results shows that the increase in the strength of concrete with treated aggregate is better than that of untreated recycled concrete aggregate. The rate of strength gain of treated RAC is higher than that of untreated RAC. The compressive strength with RACHCl gives better results than other methods. The results from table 5.2 and 5.3 are depicted in graphical form as shown in graph 5.2 and graph 5.3.

3. Split tensile test results

Split tensile test is conducted on specimens of size 150mm diameter and 300mm height. The load at which splitting of specimen takes place shall be recorded and the split tensile strength is calculated by using following formula,

$$T = 2P/ \pi LD$$

where,
P = Max load applied to the specimen
L = Length of the specimen
D = Diameter of the specimen

Table 5.4 shows the results of split tensile strength of concrete cylinder specimen.

The split tensile strength of concrete is presented in table 5.4. Similar trend is observed in split tensile strength as seen in case of compressive strength. Irrespective of the type of aggregates, the tensile strength increases as the age increases while curing. However there is a drop in tensile strength of concrete when natural aggregate is replaced with recycled aggregate. The concrete with treated aggregate shows that split tensile strength is increased as compared to the concrete made with untreated aggregate. The results from table 5.4 are depicted in graphical form as shown in graph 5.4 and graph 5.5.

Table 2. Workability of concrete

Sr. No.	Notation	Workability in mm
1	**NAC**	90
2	**RAC**	50
3	**RAC_{water}**	55
4	**$RAC_{Thermal}$**	70
5	**(RAC_{HCl})**	80

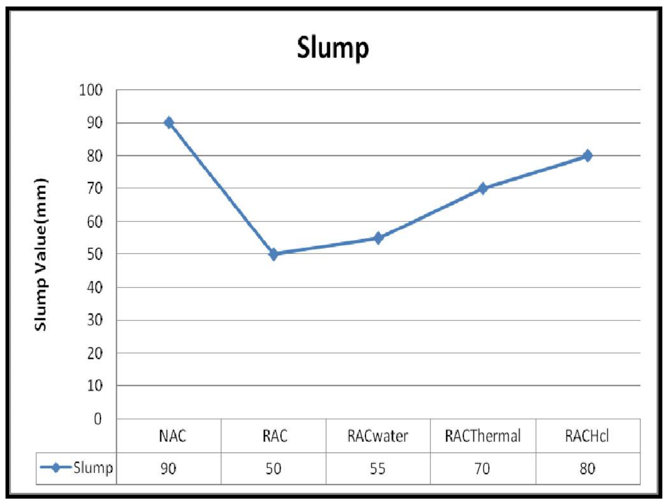

Figure 3. Graph 5.1 Slump value

Table 3. Compressive strength for M40 grade of concrete

Sr. No.	Notation	Compressive strength (N/mm^2)			
		3	**7**	**14**	**28**
1	**NAC**	21.66	32.43	43.20	49.60
2	**RAC**	15.80	27.20	33.20	38.70
3	**RAC_{water}**	16.80	27.94	36.93	40.52
4	**$RAC_{Thermal}$**	19.80	28.75	39.25	44.89
5	**RAC_{HCl}**	21.10	31.40	42.98	48.50

Table 4. Compressive strength for M35 grade of concrete

Sr. No.	Notation	Compressive strength (N/mm^2)			
		3	**7**	**14**	**28**
1	**NAC**	18.50	29.72	40.10	44.50
2	**RAC**	13.40	21.83	28.66	34.28
3	**RAC_{water}**	15.83	22.88	31.97	35.53
4	**$RAC_{Thermal}$**	16.80	26.44	36.40	40.45
5	**RAC_{HCl}**	18.91	28.70	38.20	43.40

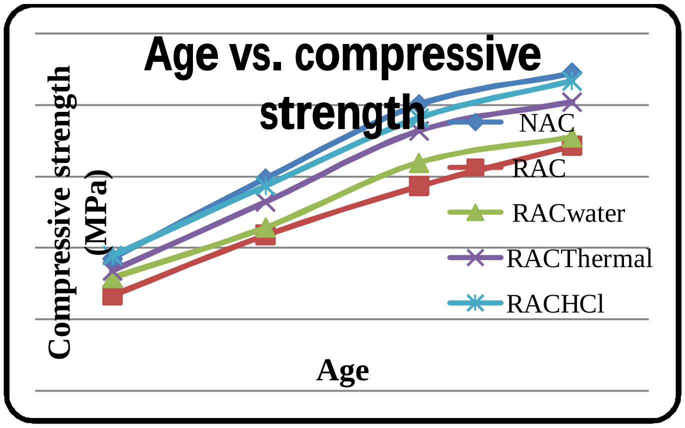

Figure 4. Graph 5.2 Age of concrete in days vs. compressive strength of M40 grade of concrete

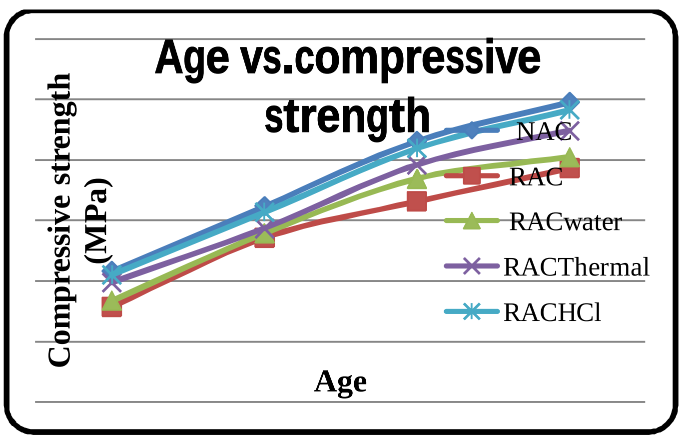

Figure 5. Graph 5.3 Age of concrete in days vs. compressive strength of M35 grade of concrete

Table 5. Split tensile strength for M40 and M35 grade of concrete at 28 days of curing

Sr. No.	Notation	Split tensile strength (N/mm^2)	Split tensile strength (N/mm^2)
		M40	**M35**
1	**NAC**	4.98	4.20
2	**RAC**	3.80	3.25
3	**RAC_{water}**	3.90	3.38
4	**$RAC_{Thermal}$**	4.28	3.85
5	**RAC_{HCl}**	4.45	3.98

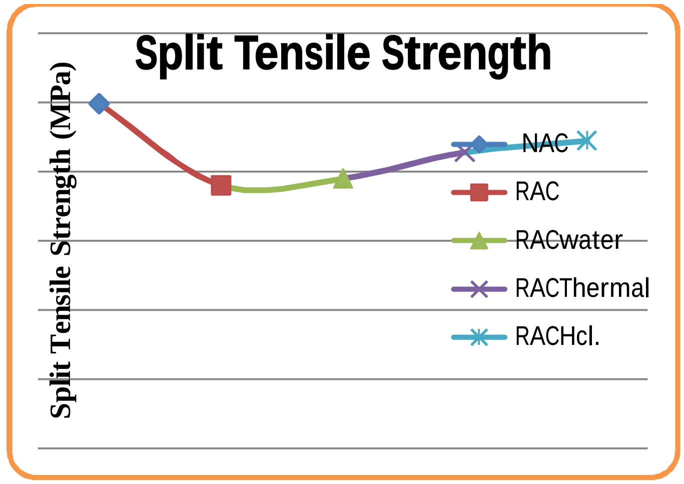

Figure 6. Graph 5.4 Split Tensile Strength OfM40 Grade Of Concrete

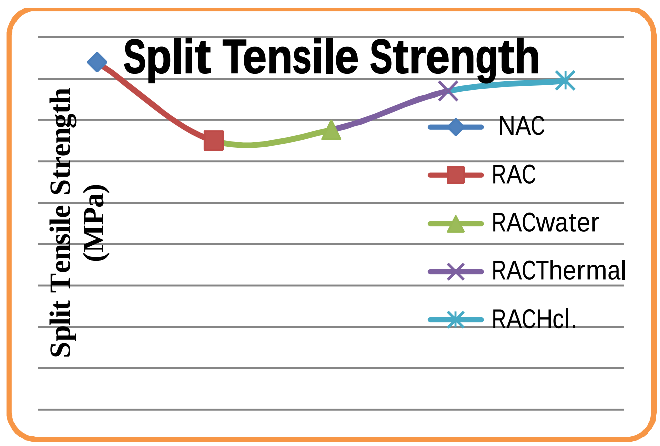

Figure 7. Graph 5.5 Split Tensile Strength Of M35 Grade Of Concrete

VI. CONCLUSIONS

From the experimental investigation it is concluded that,

1. The surface treatment method effectively removed the loose mortar particles and improves the properties of RCA.
2. The workability of concrete manufactured with RCA as well as NA was investigated, it has been observed that for RAC the slump value is 55.55% of that of the NAC and it shows better result with treated RCA. The water absorption capacity increases due to higher amount of adhered mortar on RCA. Hence the slump value of RAC is found to be lower than NAC.

3. Water absorption of recycled concrete aggregates is found to be 2.10 % greater than natural aggregates.
4. The compressive strength of concrete made with treated recycled concrete aggregates increases as compared to concrete made with recycled concrete aggregate, on the average, the RAC cube strength at 28 days of curing is 78 % of that of the NAC. The lower compressive strength is due to the presence of loose mortar on RCA.
5. The tensile strength of RAC is lower than that of NAC at all ages. However, these strength of concrete shows improvement in results with treated recycled aggregate, on the average, the RAC cylinder strength at 28 days of curing is 76.30% of that of the NAC.
6. Overall, the surface treatment by presoaking the RCA in HCl significantly improves the properties of RCA. Hence this method is considered as a beneficial method and can be employed in the application on large scale RAC projects.

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